SPECIAL SECTION: WITNESSING ENVIRONMENTS

Data witnessing: Making sense of urban air in Copenhagen, Denmark

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Abstract:

Taking air pollution in Copenhagen as a case of environmental change, this article discusses the different ways that data are employed in processes of witnessing this change. We distinguish between three different modes of "data witnessing"—modest, imperial, and guerrilla—in order to clarify how different scientific, corporate, or civil society actors are engaged in producing and analyzing data about air pollution from different vantage points and with different interests. Their respective data work, as well as their joint participation in collaboration and confrontation over the interpretation of data, is a crucial component in making sense of air pollution in Copenhagen, which is predominantly out of reach to the human senses. Witnessing air pollution in Copenhagen is made possible by critical data designs under circumstances where neither data, nor subjective witnessing, in itself is enough.

Keywords: data, environment, science, air pollution, Google, resistance

To citizens of Copenhagen, Denmark, making sense of "air pollution," and the related question of what "air quality" is, has become *more* rather than *less* complicated in recent years. Until recently, the only data about the status of air pollution in the city of Copenhagen came from three stationary sensors curated by environmental scientists and positioned in proximity to some of the city's busiest streets. Apart from data from these sensors, air pollution and air quality were assessed through modeling tools and computations, or by the citizens' bodily senses. Today, however, the limited range of particle measurements offered by these stationary sensors are both supplemented and challenged by new data gatherers and data types. On the one hand, Google's "Project Air View" (PAV) collaborates with the Municipality of Copenhagen to produce more dynamic data that can identify particle concentrations in the city with high precision and granularity. These data sets are produced by a specially designed Google Street View Vehicle circulating within Copenhagen equipped with particle sensors. On the other hand, citizen groups—sometimes armed with or inspired by the use of small hand-held "do-it-yourself" (DIY) forms of sensing, sometimes merely relying on their own olfactory senses—are stressing the importance of more widespread but situated accounts of air pollution at specific locations within the city. Air quality has become a political battleground between municipal politicians, health authorities, eco-movements, citizen preferences, and corporate interest.

This article scrutinizes how various actors interpret and make use of different data-making efforts as emergent practices of witnessing. Grounded in digital and analog ethnographic material about air pollution measurements in Copenhagen, we use the term "data witnessing" to refer to the way that witnessing of environmental circumstances emerges as a collective co-production enabled by an engagement with multiple data forms and data infrastructures, which both organizes and is organized by corresponding political ambitions (see Gray 2019). "Data," however, is not only one thing. It can be generated in multiple ways

and involve different types of knowing and expertise. We therefore focus on how three different ways of organizing the generation and employment of data each can be defined by their different ability to act as witness. One type is the stationary sensors coordinated through the general modeling by air pollution scientists in Denmark, which we characterize with inspiration from Donna Haraway (1997) as *modest witnessing*. A second is the Google-generated *imperial witnessing* aiming at subjecting the entire world to its data realm (see Zuboff 2019). And finally, we call the third *guerrilla witnessing*, referring to the irregular use of data forms and types for politically limited, specific, and situated purposes, oftentimes in resistance to established scientific, corporate, or political authorities, and sometimes working through the enhancement of bodily senses with DIY sensors (see Gabrys 2016; Pritchard, Gabrys, and Houston 2018). The three forms correspond to three groups of actors each employing their own mode of collecting and organizing air pollution data, which again affords specific types of politics. Yet they also collaborate and draw upon each other to various extents (although not always mutually). Most importantly, they are all committed to data as instrumental in how environmental changes (here air pollution) can be accessed and thus witnessed.

The article uses this differentiation between the organization of data types and witnessing to discuss the micropolitical conflicts of air pollution in Copenhagen. We have followed local debates over air pollution systematically since early 2020 through a combination of online ethnography, reading of relevant documents (policy papers, news stories, opinion pieces), and qualitative interviews.[1] We show how the conflicts between different actors and interests are put into relief by the existence of the different forms of data witnessing, and, vice versa, how these conflicts affect the employment of data. Altogether,

1. Participant observation has been difficult since the onset of the COVID-19 crisis in March 2020.

we locate our argument in between anthropological and science and technology studies literatures dealing with the scientific and political status of environmental data and scientific monitoring. The article thus contributes to debates about witnessing environmental change by discussing how data in itself can perform in processes of witnessing.

Scientific monitoring and critical data design

The question of how scientific monitoring renders environments and thereby air pollution visible is of crucial importance for the making of political as well as everyday life decisions. A dominant trend in anthropological accounts of scientific monitoring has been to focus on climate or environmental modeling and especially the uncertainty of models (e.g., Lahsen 2005; Hastrup and Skrydstrup 2013; Barnes 2016). Other key treatments of this question have demonstrated how environments or polluting substances are made perceptible (e.g., Murphy 2006), how they can be implicated in "slow violence" (Nixon 2013), how they can be traced ethnographically (e.g., Fortun 2001; Shapiro and Kirksey 2017), or how collaboration between different forms of expertise are enacted within an unruly and changing climate (e.g., Vaughn 2017). The materiality of environmental or polluting phenomena figures prominently in this research, although with different degrees of agency ascribed to the materialities in question.

There has been less focus on questions of how data are presented and become part of testimony and practices of witnessing, which is the gap we intend to address. Two notable exceptions in anthropology and sociology respectively are worth mentioning. One is Kim Fortun's work about what she refers to as the informating of environmentalism (Fortun 2004). Fortun is concerned with how environmental information systems affect how and what people see in the environment, how they deal with environmental problems, and how specific (information) technologies are more or less appropriate for this effort. The uneven

distribution of data and information pointed out by Fortun is of particular relevance to our case along with her recent discussion of the interpretative efforts involved in what she and her colleagues refer to as "critical data design" (Fortun et al. 2016). In combination with the political purpose of addressing public interest, this hermeneutic labor is critical in leveraging big scientific data sets and translating them into politically meaningful "pushbacks" through different graphical user interfaces and visualizations. This emphasizes how interpretative data design enables the crossing of different domains of knowledge.

The other notable exception is the sociologist Jennifer Gabrys's work on digital sensing and the construction of environmental data in new "technogeographies" that connect technology, environments, and people (Gabrys 2016; Pritchard, Gabrys, and Houston 2018). Of particular interest is her use of the term "withness" to criticize notions of the smart city, and to discuss and signal "modes of being and becoming together … such that the possibilities for both urban ontological engagements as well as urban speculative futures are undertaken" (Gabrys 2016: 242). "Withness" is not meant on Gabrys's part as a wordplay on witnessing, but we choose to engage her work with such a pun in mind, because it raises "the question of how we 'possess' the world and become together, not exclusively as a matter of intelligence or rational cogitating actors, but as embodied if differently directed creatures in shared worlds" (ibid.: 243).

When environmental problems are characterized by invisible pollutants, then data design has a critical ability to link public problems with the oftentimes highly complex datasets. Figuring out how pollution is best rendered visible is a challenge involving multi-disciplinary efforts bridging different types of data, different types of knowing and expertise, and different political concerns (Vaughn 2017). Connecting pollution data with human health effects, ecosystem deterioration, or atmospheric conditions has historically been a challenging task as the health and pollution sciences have been separated into different

government agencies and domains (Fortun et al. 2016: 2). However, through recognition of the multiple and diverse factors shaping data availability and use, data designers may invoke specific forms of politics by allowing users to witness environmental change, which would otherwise be out of reach to the human senses. Yet, this demands that the technological design is constructed with the appropriate affordances and attuned to the particular needs of the setting where it is supposed to work, as exemplified by the Scorecard website studied by Fortun (2004). The Scorecard website displays similarities to some of the data presentations made for air pollution in Denmark, which we turn to below.

Witnessing air pollution in Copenhagen

The World Health Organization estimates that nine out of ten people around the world breathe air containing pollutants exceeding their guidelines (World Health Organization 2021). In other words, human beings live and act in a "permanently polluted world" (Liboiron, Tironi, and Calvillo 2018). Yet, air pollution can be colorless, tasteless, and odorless. In many places it is an invisible threat difficult to detect by ordinary senses. As a Western capital city with approximately two million people living in the wider metropolitan area, Copenhagen exemplifies this dilemma. One could suspect that inhabitants of a city of this size would sense significant pollution from transport and industry, but the city is located favorably on the coast, for one thing, and secondly environmental regulation from 2006 has allowed Copenhagen to be a low emission zone with strict limits particularly on the exhaust from heavy-duty motor vehicles (Danish Environmental Protection Agency 2021). This has eliminated some particle types. Yet, the effect is uneven. There are sites where air pollution is a contentious issue both in the city center as well as in the suburbs, and levels of nitrogen dioxide (NO_2), for example, have in some streets repeatedly exceeded EU limits. The rapid growth of traffic in and out of the Copenhagen Airport, which is located a mere eight

kilometers from the city center, has been especially subjected to critique, which we will outline below.

In order to make particle concentrations visible, the Municipality of Copenhagen has allied itself with both traditional scientific modes of measurement and the PAV introduced by Google. They stress public-private partnerships as a means to generate "smart green growth" (Copenhagen Solutions Lab 2021b), which is connected to a general political admiration and embrace of digitalization and data-driven solutions among Danish politicians and public servants aiming to make Denmark one of the most digitally advanced countries globally (Schou and Hjelholt 2018). It is within this context that data has emerged as central to practices of environmental witnessing in Copenhagen, and why data witnessing works as an apt ethnographically driven theorization of the processes of converting the three above-mentioned forms of monitoring into environmental politics through the intermediary of critical data work (see Fortun et al. 2016). Needless to say, governing air pollution in a site like Copenhagen involves a host of different technoscientific, industrial, and political actors, each contrasting, probing, or borrowing each other's expertise (see Vaughn 2017). In order to address the difficult ontological vantage point, where multiple actors are involved in determining the health and environmental effects of a largely invisible source of pollution, we combine the focus on data with the notion of witnessing in order to make sense of the positions and the forms of knowing and action pursued by the different actors involved.

Joining the concepts of witnessing and data

The notion of witnessing is predominantly associated with being present and constructing a testimony based upon first-hand accounts of an event seen, heard, or experienced by the present people acting as witnesses (see Das 2003; Fassin 2008). In ethnographic work in particular, witnessing has conceptual overlaps with fieldwork practices of observation and

participation (Reed-Danahay 2019), and Clifford Geertz (1989) most famously debated the entanglement of witnessing with the "I" of said witness. It may seem a contradiction in terms to combine this notion of witnessing associated with "subjective" human views based upon first-hand presence, with that of data, which in lay understanding is often regarded as "objective" representations of reality, even when numbers are transformed into audiovisual media, or when digital media can catch details imperceptible, distorted, or lost by human memory (Peters 2009: 24).

It is the case for air pollution in Copenhagen that it is not easily smelled. It is approached in a technologically mediated form as data about specific particles. Our argument is that this combination of data mediation and human sentience performs a new type of witnessing that engages the co-productive potentials of different data forms. While we do not want to go so far as to claim that data has gained a life of its own, we do want to emphasize how opportunities for data collection and analytics today are transforming what it means to witness something both for our interlocutors and for the ethnographic work of following their attempts to make sense of urban air. It demands an ethnography of data practices including their collection, presentation and interpretation (Fortun et al. 2016).

Taking a cue from anthropological debates about data, it is important to stress that the recent proliferation of data as both a popular term and a focus for IT-based research practices in the social sciences has meant that data gathering practices as well as the categories of what data "is" and what data "represents" have been in need of rethinking (see, e.g., Boellstorff and Maurer 2015). As new forms of (digital) data have become central to social scientific research (e.g., Rogers 2013; Pink et al. 2016; Dalsgaard 2016; Knox and Nafus 2018), any attempt at a sharp delineation between uncertain (human) witnesses and certain (nonhuman) data has itself come into jeopardy through a critical social scientific gaze (e.g., Gitelman 2013; Kitchin 2014; Garnett 2016). Yet, the idea that data can represent a one-to-one

rendering of reality has been undermined by accounts of how data is generated in practice. Just as witnesses can be unreliable, so can data. The metaphor of "raw data" has been claimed to be potentially misleading because such data are regarded by scientists as uncertain and untrustworthy because they can be filled with errors. The metaphor itself obscures the infrastructures and labor of cleaning and curation involved in generating these data and what they represent (Walford 2017: 68). As with "ordinary" witnessing, however, the testimonies made by data—raw or "cooked—can be embroiled in partiality, situatedness, or even affect. This critical view of data is necessary to keep in mind when contending that data can be considered as performing an act of witnessing in itself.

As a basis for combining this scrutiny of data with a notion of witnessing, we lean on the work of Jonathan Gray (2019), who has proposed the term "data witnessing" to refer to the multiplication of involvement of distant actors in the witnessing of events. Gray's conceptualization draws upon a number of other witnessing labels and definitions, such as "digital witnessing" or "media witnessing," which focus on the construction of moral engagement from afar, mediated through various technologies or forms of media content. Gray analyzes the digital data practices of Amnesty International's Decoders initiative and discusses the configuration of witnessing of injustices with data from various sources (e.g., social media, satellite imagery, official reports, photographs, eyewitness interviews). This is, as we read it, an approximation of data—in an organized and assembled form—becoming implicated in the performance of witnessing in itself. The accounts Gray is concerned with do not gain their authority from the presence of individual human witnesses alone. Instead, data witnessing is about the collective yet distributed rendering of injustices as systemic. Data witnessing configures the scale of witnessing across space and time and opposes it to a focus on isolated events and "the 'thereness' of singular personal experience" (ibid.: 986).

Like the notion of "virtual witnessing" (Shapin and Schaffer 1985), which Gray draws upon, data witnessing involves the construction of collective dimensions of witnessing, and in line with Bruno Latour's work (1993) it relies upon nonhuman actors and their testimony. While Gray demonstrates this for the work of documenting and exposing injustices and violations against human beings, it is equally pertinent for environmental topics, where sensors, microscopes, and accumulation of other technological intermediaries are crucial to the natural sciences as extensions of human bodily perceptions and senses in constructing an image of environmental injustices or violations (see Shapiro and Kirksey 2017). As demonstrated by anthropologists researching environmental engagement, the data and how data are presented (through models or visualizations) does more than merely "mediate." It actively creates something (Hastrup 2013; Vaughn 2017). In our case a sense of witnessing.

We now return to our field site of Copenhagen, where our digital ethnographic material allows us to identify three different ways of generating, organizing and employing air pollution data. Each way can be defined by its ability to produce forms of data that act as witness in relation to specific political purposes.

Modest witnessing

Air pollution scientists from the Danish Center for Environment and Energy (DCE) at the Department of Environmental Science at Aarhus University are engaged in what we, with inspiration from Haraway (1997), characterize as modest witnessing. This department has for more than thirty years been responsible for monitoring air pollution levels in Denmark in collaboration with the Danish Environmental Protection Agency and other research institutions in Denmark. The efforts of the program consist of data collection from more than twenty stationary sensors located across the country (with three in Copenhagen), supplemented by a dozen mathematical models. Some stations are located in heavily

trafficked streets in the four largest cities of Denmark, others have been placed on roofs or in backyards in cities, while some measure air pollution in coastal or rural areas. The air pollution substances are recorded according to EU standards and include, but are not limited to, nitrogen oxides (NO_2, NO_x), ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), and particles sized PM10 and PM2.5 (also known as "fine particles"). The measurements for each can be accessed through charts and diagrams on the DCE website (DCE 2021). The stations monitor the different substances using various methods in accordance with each targeted substance. This implies that some measurements need long-term data collection which is subsequently analyzed, whereas other instruments can deliver immediate analysis of daily measurements.

In addition to the network of monitoring stations, the Department has developed a suite of twelve different air quality models, each of them built with a specific purpose in mind. The "Atmospheric dispersion model," for example, is applied for regulatory purposes, whereas the "AirGIS" model is used for urban air quality assessment. The "Economic valuation of air pollution model" is used to determine societal costs of adverse human health effects from air pollution exposure, and the "THOR model," combines other models to produce the "3-day forecast for air pollution in Denmark" (Department of Environmental Science 2021). It is an interactive, animated air pollution map of Denmark which renders visible the concentration of six different air pollution substances (ozone, NO_x, NO_2, CO, PM.2,5, PM10) at a granular level of one square kilometer. Website visitors can choose a pollutant and observe how the pollution level is predicted to change on an hourly basis over the course of the next three days (Figure 1).

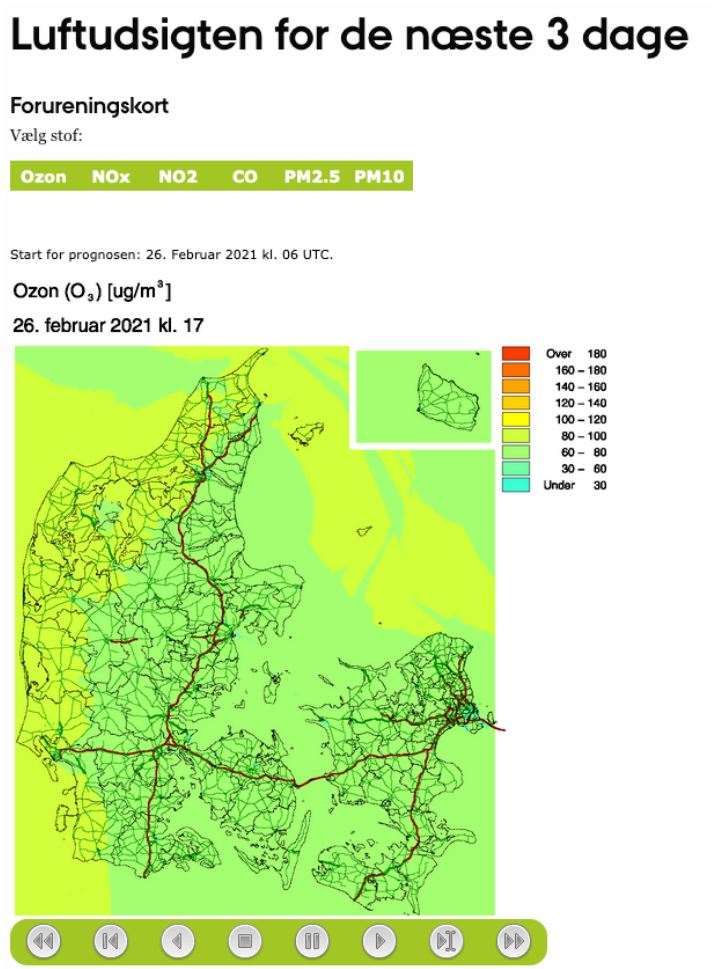

Figure 1: The DCE's 3-day forecast for air pollution in Denmark (Department of Environmental Science 2021, accessed February 26, 2021).

The major guiding principle for this scientific work is to assess particle concentrations against politically determined air quality standards outlined by the European Commission (2019). To do so, the monitoring program is organized according to classic scientific criteria. Its claim to scientific validity comes from systematic data collection with methods of measurement specifically tailored to each particular substance. The equipment is furthermore tested and calibrated according to established international standards, and the methods and results are openly available to the public through the Department website. In this way it is available to interested stakeholders including citizens, NGOs, governing bodies, and experts, yet many of the representations of air pollution still require a certain level of familiarity with

threshold limit values and quality standards, as well as knowledge of the scientific nature of air pollution to make sense of the data (Nafus 2018). The design of the three-day forecast for air pollution in Denmark succeeds in highlighting how air pollution in Denmark is predominantly affected by sources stemming from neighboring countries. However, in contrast to similar applications such as Scorecard (Fortun 2004), the coarse-grained nature of this map makes it more or less irrelevant for citizens of Copenhagen. It does not allow them to take any meaningful action in relation to the information provided, and it does not hold the same affordance for political mobilization as Scorecard.

While it may be a stretch to argue that the scientific work of the DCE amounts to modest witnessing in the exact sense described by Haraway (and through her also by Gray), it still does so on a number of parameters. Haraway's account has been central in the feminist destabilization of scientific assumptions of disembodied objectivity and privileged perspectives. In her book *Modest_witness@Second_Millenium.FemaleMan©_Meets_OncoMouse*™ (1997), she takes the term from the work by Steven Shapin and Simon Schaffer (1985) on the seventeenth-century dispute between Thomas Hobbes and Robert Boyle, a dispute which lead to the foundation of experimental science. Most importantly, Shapin and Schaffer argue that "if knowledge was to be empirically based …, then its experimental foundations had to be witnessed" (ibid.: 55-56). As with the overarching notion of data witnessing as described by Gray, the construction of scientific facts relied on public and collective contributions. The witnesses during the times of Boyle and Hobbes had to be gentlemen, whose moral constitution and thus their testimony could be trusted to be credible and reliable. The ideal was "a modest man," and Haraway emphasizes how the white male scientist was made invisible in order to enforce "the virtue of modesty" (1997: 23), a virtue which "guarantees that the modest witness is the legitimate and authorized ventriloquist for the object world,

adding nothing from his mere opinions, from his biasing embodiment …. His subjectivity is his objectivity" (ibid.: 24).[2]

Neither Shapin and Schaffer nor Haraway have touched upon the status of the data produced in these experiments as such. The ontological status of data at their time of writing was naturally not what it is today, but even now, data itself is by positivist natural science often perceived to be the objective yet "raw" representation of a reality: the witnessing of reality independent of a human subject that appears when facilitated by correctly calibrated equipment and data infrastructures (see Walford 2017). Haraway could easily have concluded this when she cited Shapin and Schaffer: "The experimental philosopher could say, 'It is not I who say this; it is the machine'" (1997: 25), as if the machine was the actual witness. Because we stress this shift in focus away from the scientist and on to the data, we also stress that data witnessing implies a process (as in modest witnessing) rather than a figure (the modest witness).

The scientists of the DCE most clearly act as modest witnesses through their attempts at constructing neutrality and distancing between subject and object, that is, making invisible (transparent) the many practical operations, their scientist operators, and any relationality behind them (see Haraway 1997; Walford 2017). For example, the visualizations of the DCE's models obscure or eclipse the actual work of witnessing performed by the sensors. There is in this mode of performing data witnessing little identification with the data or with the context where the data is collected. While methods are clearly outlined, there is no elaboration of the curating of the data from "raw" to "clean" (see Walford 2017). The DCE

2. To be sure, Haraway's preferred ideal for the figure of a modest witness is instead "historically specific, located in a particular time, place, and body" (1997: 20). Her version of modesty is about a critical immersion where questions about race, class, gender, and sex can be raised for the purpose of dialogue, care, and accountability.

visualizations and models resemble the Scorecard website on this parameter of only providing interactive information and not the raw data itself (Fortun 2004).

In a lay sense of the term "modest," there is furthermore a reliance on the combination of (relatively) few sensors and purpose-specific models. In spatial terms data collection is rather modest due to the relatively low number of stationary measurement stations situated across the country, but the datasets are comprehensive over time, and they record a wide variety of particle types. Yet they leave the largest job to be performed by the models. When it comes to the models, they can be deemed modest because of their limited scope and focus, and because of their inaccuracy as coarse-grained calculations rather than measurements. Of our three types of data witnessing, the modest witnessing is thus the one farthest removed from being a collective and distributed accomplishment as stressed by Gray, even if it is intended as input to policy debates and is employed by citizens for specific purposes, as we shall see below. In comparison, the PAV, to which we now turn, has a higher granularity, and claims to be positioned closer to citizens as potential users of their air quality maps.

Imperial witnessing

The PAV was welcomed by the municipal government of Copenhagen as a way to help counter criticism from the EU Commission that the city did not live up to the EU regulations on NO_2 emissions (Saietz 2016; Krog 2018). A more fine-grained mapping of air pollution in the city was thought to be able to improve urban planning and reduce local sources of emissions. In order to provide these data, the PAV collaborated with both the researchers from Aarhus University mentioned in the previous section, as well as scientists from the University of Copenhagen's Department of Public Health, and Dutch scientists from Utrecht University, who helped equip the Street View Vehicle with state-of-the-art sensors and data collection itself.

According to the PAV, data has been collected in Copenhagen by a sensor-equipped Street View Vehicle Monday through Friday during daytime hours, typically between 9 a.m. and 6 p.m. The measurements shown in the preliminary PAV map—the Air Quality Explorer (AQE)—represent an estimation of the median pollution from November 2018 through August 2019 in individual streets. Street measurements have been repeated with multiple passes by the vehicle in order to reduce the influence of individual extreme samples and to ensure that the measurements are truly "hyperlocal."[3]

Despite claims to exhaustive coverage through mobility and "hyperlocality" mentioned in a promotional video with Country Director for Google Denmark, Malou Aamund (Make Sense Film 2018), not all streets of Copenhagen are included in the AQE. A number of narrow and mid-sized streets are not (yet) included, and a few larger streets are for unknown reasons either absent or only partially covered. The Municipality of Frederiksberg which covers a large geographic area of the city is also not included. The Copenhagen Airport (CPH)—normally expected to be a large source of pollution—is located a few kilometers south of the municipal border and also not covered. Yet the citizen group named *CPH uden udvidelse* (Danish for "CPH without expansion"; see CPH-UU 2021) has copied one the AQE maps to its website in order to argue that the Airport could do more to limit its emissions. We will return to this group below.

Furthermore, not all types of particles are presented in the AQE. Copenhagen's AQE focuses on black carbon (BC, or "soot") and ultrafine particles (UFP). At first glance, then, the witnessing appears partial at most and not holistic as one would expect of any of Google's ventures. However, the AQE maps display Google's attempt at covering all streets that could realistically be navigated by the Street View Vehicle, and while the publicly available

3. A description of the methodology that was used in Oakland, California, has been outlined by Apte et al. 2017.

preliminary maps and visualizations only refer to BC and UFP (see Figure 2 below, from Google 2021), the Street View Vehicle was also meant to measure levels of PM10, CO_2, and NO_2 (Copenhagen Solutions Lab 2021a). Given Google's previous history and imperialist ambition (see Zuboff 2019), the vehicle was possibly collecting other types of data too, which allows for more nuanced forms of analysis and data presentation (cf. Apte et al. 2017).

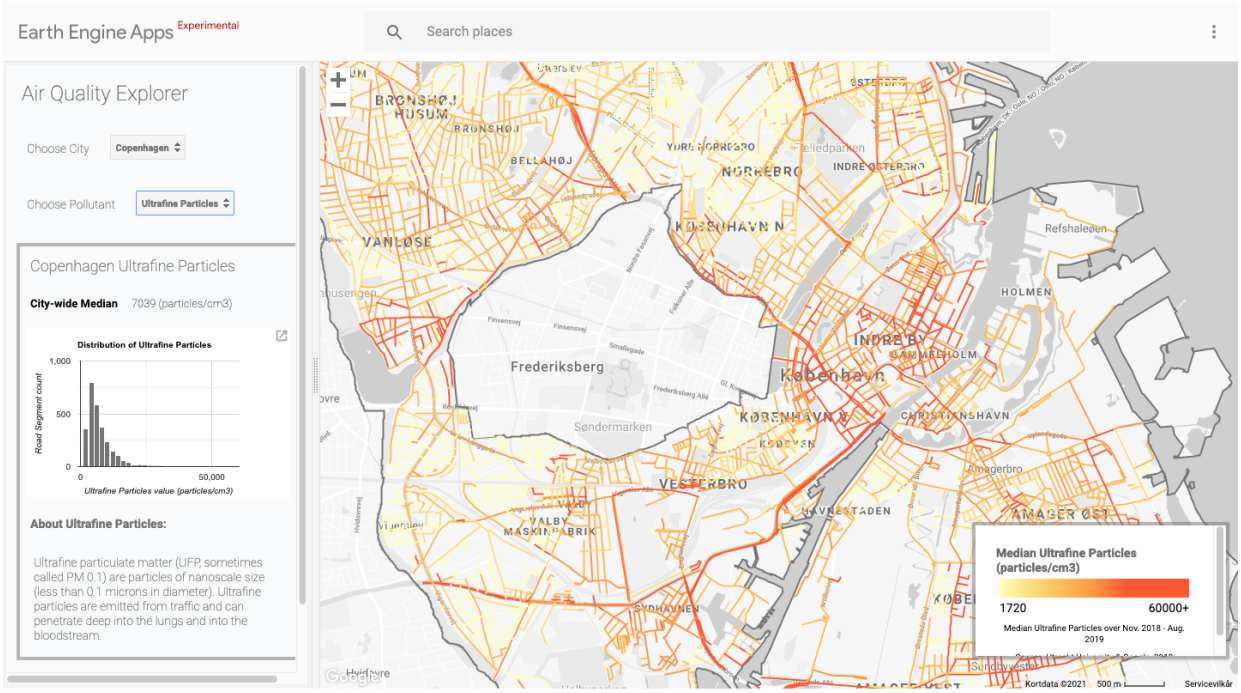

Figure 2: Google Environmental Insights Explorer. From https://insights.sustainability.google/labs/airquality, as of March 2021.

It is unlikely that altruistic help to a municipal government has been Google's only incentive. Data is the prime resource for Google (or Alphabet, as the mother company is named). It has become notorious that the founders Larry Page and Sergey Brin aim to "organize the world's information and make it universally accessible and useful" (cited in Moore and Tambini 2018: 4). This ambition to collect and organize all the world's information has not only been accused of being an exertion of dominance over human

knowledge, but also of wanting to use this knowledge to exert surveillance and make profit from the possession and curation of the multitude of data constantly generated around the world (Zuboff 2019: 115). As a popular critique has it, Google's ambition implies capturing and controlling "every cache of productive information that currently existed on, or could be ported to, the web" (Galloway 2017: 147). Search results for web content were not enough for their goals: Google has gone on to impose itself as a gatekeeper of access to locations (Google Maps), astronomical information (Google Sky), geographical information (Google Earth and Google Ocean), books (Google Library Project), and journalism (Google News), not to mention the knowledge and control of human behavior through these services.

One of the most powerful recent discussions of Google and the other tech giants' role in global capitalism is Shoshana Zuboff's *The age of surveillance capitalism* (2019). She labels Google as "the pioneer, discoverer, elaborator, experimenter, lead practitioner, role model, and diffusion hub of surveillance capitalism" (ibid.: 63). In her view, the company's data accumulation stems from a "surveillance-based logic of accumulation" (2019: 115), which not only depends upon a process of digital dispossession, but also actions, materials, and techniques defending this business model from democratic oversight (ibid.: 99-100). In its enterprises, Google aims at mapping its data objects exhaustively (. Zuboff 2019: 154; see also Farman 2010). Examples of the exhaustive, pervasive, and holistic nature of Google's capture of data includes how the Street View Vehicle is so comprehensive and detailed in its coverage and creation of the Google Map and the Google Street View that it has been assessed to get Google's representations to be closer than any other representation available to bridging the gap between the information available in the real offline world and the information of the map (Zuboff 2019: 149-50).

Google's Environmental Insights Explorer is one of the most recent initiatives in Google's data-imperialist ambition (see Google 2021). As of March 2021, more than 3000

cities worldwide were included in this mapping of urban environmental data. For each city Google estimates CO_2 equivalents for buildings and transport while providing a CO_2 reduction potential for cities with regards to equipping rooftops with solar panels. Within this framework, the PAV is highlighted as a new critical indicator for climate action. Copenhagen and London are currently the only "labs" for air quality measurements under the PAV, but the program is allegedly expanding to other cities across the world (Make Sense Film 2018; Google 2021). The PAV is described as a game changer by bringing novel kinds of data together in new ways, thereby making environmental problems more visible and actionable. This framing resembles other critical data designs such as the abovementioned Scorecard (no longer in operation) or the US Environmental Protection Agency's EnviroAtlas, both of which have aided decision makers and users by linking pollution data with other issues (Fortun et al. 2016: 3). The current AQE is a preview that can currently only be accessed through larger devices, while support for smartphones is in the making. The preliminary measurements are currently being tested and the final map, which has been delayed due to COVID-19, is set to launch during the summer of 2021. Google's aim is to connect the AQE to the Google Maps application to allow citizens to navigate and avoid the most polluted streets. This focus on helping citizens avoid pollution is allegedly what was meant by Aamund's reference to hyperlocality. In contrast to the DCE's coarse-grained national three-day pollution forecast renderings, Google's more intuitive and fine-grained map thus allows citizens to act upon its data presentations. Yet, such use of the application is likely to generate more data for Google about citizens' preferred routes and whereabouts, which would contribute to the expansion of their data empire. When or if citizens start to navigate differently in urban space as a result of their interaction with the PAV, its measurements and its maps, then Google will know immediately and learn how the environmental data will affect behavior, in turn generating better predictions of human behavior and more value for

the company. The PAV is an attempt to create an *individualized* data witnessing rather than the collective effort emphasized by Gray (2019), and while it may be easy for citizens to appropriate it for some of their needs, it may not as such be an "appropriate technology" (Fortun 2004), to which we return shortly. Rather than embracing local perspectives, Google's form of data witnessing is more likely to be an attempt to scale and bridge the local and the global through massive datasets to further underwrite the company's imperial ambitions.

Guerrilla witnessing

The third form of data witnessing we have encountered in our ethnographic material is what we refer to as "guerrilla witnessing." Guerrilla witnessing is built upon data collection done by scientists and lay people interested in specific experimentations with sensors, data collection methods, or activist mobilization,[4] or pursued by NGOs, companies, or government agencies trying to collect data from more scattered sources. This form of witnessing thus has parallels in what is referred to as self-tracking (e.g., Eede 2015; Lupton 2016) or mundane data practices (Pink et al. 2017), and it includes (but is not limited to) the DIY measurements of air quality undertaken with a variety of mostly low-cost digital sensors (Gabrys 2016; Pritchard, Gabrys and Houston 2018). The civil society group we have followed makes use of a variety of ways of assessing air quality, and the different modes of witnessing become entangled as overlapping but also sometimes contrasting forms of expertise in their endeavor (cf. Vaughn 2017).

In March 2016, the Copenhagen Airport announced the initiation of a major expansion aiming to double the annual number of passengers. This was not welcomed by

4. A "guerrilla example" with the participation of social scientists is a project at Aalborg University (see Public Data Lab 2018).

citizens living in the vicinity of the airport, and in June 2019 the citizen group CPH-UU was formed in response to news of the expansion (Flensburg 2019; CPH-UU 2021). The group is highly active in a public Facebook group where we engaged with them and have been able to follow how nuisances related to noise and smell are discussed. Some group members express their dissatisfaction with the current conditions by posting messages on the public Facebook sites of national politicians while others write opinion pieces in local newspapers. In an interview with one of the most active members, she highlighted that the increase in smell and noise in the neighborhood close to the airport had made her consider "whether it is still a good place to raise our children." During the past decades the number of passengers traveling through CPH Airport has increased from seventeen million in 1998 to thirty million in 2019 (CPH Airport 2021). Especially in the last three to four years conditions are reported to have worsened for neighbors of the airport. The number of complaints from concerned citizens and workers about air or noise pollution around the airport increased from twenty-seven in 2017 to 674 during 2019 (Bjørton 2020b). The CPH-UU group is not against the airport as such—they perceive it to be an important employer for the local community—but they are against the expansion because of the expected rise in nuisances.

In their attempt to stop the expansion, the CPH-UU has been trying to introduce both novel forms of information-gathering about noise and air pollution and new ways of mobilizing resistance. The airport produces its own measurements, but the local government has opted to bring in scientists from the DCE as consultants to conduct an independent assessment related to the concerns of the CPH-UU group (Bjørton 2020a). The combination of corporate (airport) measurements and scientific monitoring, which is largely based upon modeling, has not fully satisfied the CPH-UU. During our work with the CPH-UU group, it became clear to us that some members suspected the airport of not being fully transparent about its measurements. The group is furthermore concerned with peak occurrences, rather

than the averages which count when it comes to the official threshold limit values monitored by the DCE. Due to the lack of air pollution measurements near the airport, the group has tried to bring in more measurements from residential areas covering a larger radius than the current monitoring practices which primarily rely upon modeling (CPH-UU 2021). A complicating factor has been the difficulty of establishing a clear scientific consensus about how hazardous high concentrations of UFPs stemming from jet fuel and fossil fuel-powered vehicles actually are to human health (see Kumar et al. 2014: 7). The lack of scientific consensus means that the Danish state has not set any threshold limits for this type of particle in correspondence with EU targets. Members of CPH-UU have tried to fortify their position by bringing scientific work from other sources into the public discussion—for example, a study which documented that exposure to the exhaust of aviation fuel is as harmful to mice as that from diesel engines which are already known to have adverse health effects (Bendtsen et al. 2019; see also Fuller 2019: 127).

In a strategy aimed at raising public awareness, the CPH-UU group has stressed the vicinity of the airport to the center of Copenhagen (eight kilometers). This is less than most other airports of comparable size, and well within the radius where particles may have a significant effect on people's health (Fuller 2019: 125-26). This mobilization also includes the group's adoption of the processes of witnessing enacted by DCE and Google. The stationary measurements conducted in Copenhagen and the measurements of the Street View Vehicle are both referred to, and the map of the AQE of UFPs is reproduced on the CPH-UU website. The group's interpretation of the AQE map is that streets situated in close proximity to the airport display high levels of particle concentration because several smaller streets in the area indeed are displayed with the red color indicating a higher particle count than comparable streets in other suburban areas.

Finally, the group has developed and promoted an app called Miljømåler—CPH Uden Udvidelse (Danish for "Environmental Measurer—CPH Without Expansion"). In contrast to the data designs of the modest and imperial forms of data witnessing, which rely on sophisticated technoscientific technologies, CPH-UU's app has, according to their spokespeople, been built with the sole purpose of raising political awareness. Due to the lack of measurements near the airport, the group has felt compelled to develop the app to register and report discomfort due to noise or air pollution based on their location (see Figure 3). Once the discomfort is registered by a user, it is sent directly as a citizen complaint to the Danish Environmental Protection Agency. Using an embedded Google map, the app allows citizens to record experiences of nuisance without using any kind of measuring device, although it is possible to add decibel volumes when sending a complaint about noise. In contrast to the DIY cases described above (Pritchard, Gabrys, and Houston 2018), users of the app can report "air nuisance" or "noise nuisance" based entirely upon their individual bodily experiences.[5] The introduction of the application in November 2019 may not carry sole responsibility for the increase in complaints, but the app does enable faster and more convenient reporting of nuisances. Yet it does so in ways that are so far not integrated with scientific measurements.

5. Some neighbors living three kilometers from the airport were interviewed by a major Danish newspaper in July 2019 and stated that they could often "smell and taste the airport" when they were in their garden (Flensburg 2019).

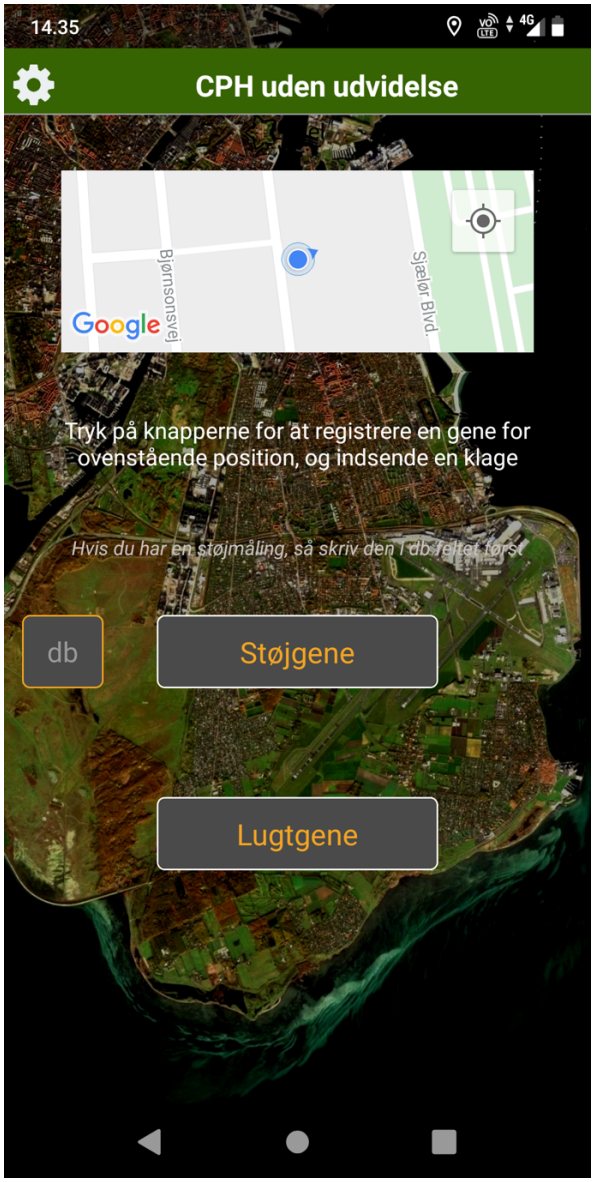

Figure 3: Environmental Measurer—CPH-UU.[6]

It is aims and activities such as these that we see as characterizing guerrilla witnessing. By the term guerrilla we highlight how DIY sensing, but also uses of data generated elsewhere by scientific or corporate actors, is conducted through the attempted use of technoscientific tools and methods in an irregular and uncoordinated fashion by "parascientific actors" (NGOs, citizens, lobby organizations). They pursue a political purpose

6. The app is available in the Apple App Store and Google Play Store.

such as a participatory and democratic engagement with environmental issues, or the resistance to more powerful and resourced actors—state or corporate. At the same time, the term guerrilla is as much meant to emphasize the disruptive and unreliable nature of this form of sensing in comparison to scientifically validated sensing practices, in part because even "plug-and-play sensors" demand considerations of how they are to be calibrated and situated. The people or organizations employing these sensors attempt to ensure accuracy, commensurability, and interoperability of their results through a labor of calibration and adjustment to standards, but this work is riddled with complexities and differing approaches (Pritchard, Gabrys, and Houston 2018: 4534). Thus, DIY sensing as an example of guerrilla witnessing remains closer to a contextual relationship to the locality (see Gabrys 2016: 165).

The situatedness of guerrilla witnessing can here be contrasted to both the potential distancing as well as the generalizing scope performed by both the imperial witnessing (global) and the classic modest witnessing (national). Gabrys's notion of withnessing is worth emphasizing, because it points to both the characteristics of DIY sensing as a form of witnessing, and the activist use of data in resistance to distanced modes of generating records and witnessing. Withnessing is situated and localized; it works through embodiment in the witnessed world, which is more direct than the other two modes of data witnessing. It is thus closer to traditional ethnographic understandings of witnessing. Withnessing is not to be read as a mere postphenomenological understanding of the world as mediated through data and technology, though. It also emphasizes the collectivity involved in data witnessing.

It is clear from the above that the CPH-UU mobilizes a variety of regular and irregular data types and sources with the aim of generating concerns among fellow citizens in resistance to the major airport expansion. When the Environmental Protection Agency expressed annoyance about the number of complaints they were receiving through the app, the group replied in a letter shared in their public Facebook site that

> the discussion is not just about the app, but a broader discussion of what the complaints indicate, the existing guidelines and threshold limit values; the need for independent measurements and which demands one can raise against CPH in relation to noise and air pollution. (our translation from Danish)

The group, in other words, tries to refer to the felt and bodily experienced interactions with air pollution as an appeal to solidarity; they attempt to turn the individual experiences into a collective withnessing, thus moving beyond the "thereness" of singular experiences (see Gray 2019: 986). This includes stressing peak measurements rather than just threshold limit values as calculated averages and prompting the need to raise concerns as a collective endeavor. The guerrilla witnessing of CPH-UU is in this sense emphasizing an embodied witnessing position in comparison to disembodied modest and imperial witnessing. Yet, it is not because the group does not want the scientific data. It is because they can neither scrutinize nor control the measurements and calculations made by the DCE on air quality, nor can they effectively see the measurements made by the airport. Being unable to sufficiently account for the daily nuisances of air and noise pollution in a scientific language, or have their area fully covered by the PAV, citizens must rely upon a combination of generally available but limited scientific work and their own bodily and mundane experiences represented through the app (cf. Pink et al. 2017).

Witnessing environmental change through data

It is clear that data alone is not enough for our actors. Each actor has their own concerns—quality of models and data, expansion of territory covered, bodily sensed noise and smell. What is needed for all of them aside from *more* data, is *more than* data. This "more than" is the establishment of data as enacting a form of witnessing which facilitates public concerns and (new) political agendas. For instance, what makes the PAV valuable in local contexts is

the debates over air pollution that its presence engenders. For this, the PAV relies on collective engagement and a forging of alliances (for example between Google and the scientists of different universities including Utrecht, Aarhus, and Copenhagen). Google is potentially the most dominant actor here, because it has the resources and flexibility to expand beyond what binds the other actors. In the future we may see Google's imperial ambitions encompass new types of data encapsulated by the other modes of witnessing. Their role as a corporate empire is to sweep up everything that can be collected, packaged, and sold as data. In this way Google may as easily be an ally of the state as it may be undermining it and supporting or facilitating different forms of guerrilla witnessing.

Whereas the guerrilla witnessing taking place through situated sensing lends itself more directly to political engagement than the distance entailed by the modest ideals of science, or the imperial ambitions of Google, Gray's (2019) invitation to think about engagement with data as a form of witnessing helps us explain how the scientific results of the two latter may also generate identification or affective responses through the very mundane collective work of making complaints and sensing air or noise, as well as in debates or disputes when data are presented via enticing visualizations as displayed in the AQE or the DCE's website.

There is still much to be said about the ways the different actors perceive the witnessing of environmental change, and much that our discussion here cannot cover without continued empirical scrutiny. One point, however, is that all the actors endeavor to find not only the most *correct* but also the most *useful* data to engage in data witnessing. Whether their focus, for instance, is CO_2, BC, or UFPs depends on whether their concern is to manage climate change, monitor citizen health, mitigate noise and air nuisances or all of them at once. This should not be read as a mere cynical opportunism, but an attempt to enact the most pragmatic political and public concern, for instance in terms of helping policy makers in

constructing nuanced and informed decisions about urban planning or mobility. Some may consider, for example, the PAV to be superior in this regard to both the localized monitoring of scientific stations as much as the DIY sensors because of the formers' fine-grained scope and mobility. Yet without scientific consensus regarding UFPs and full transparency of what is collected and how it is curated by Google's data processing (Nafus 2018: 234), the authority of imperial witnessing may be questioned, which some members of the CPH-UU actually did in their internal discussions on Facebook. Our various actors then also search for the most authoritative form of witnessing. Whether authority of data comes from the construction of a virtue of modesty and distance to the object, or a situated perspective which acknowledges that data generation is embroiled in a political position, is an ongoing struggle.

Conclusion

All in all, the data generated by both the DCE scientists and the PAV is meant to aid urban planners, policymakers, healthcare professionals, and citizens alike in making smart decisions that contribute to welfare, health, and efficiency in Danish society. However, what is understood as smart decisions or appropriate technology (Fortun 2004) is here a matter of perspective, and one form of data witnessing alone does not suffice or carry automatic authority. The Municipality of Copenhagen is working to create data-driven solutions that suit the city and its citizens. It is thus vital for the Municipality to learn how the introduction of different types of data into public debate, planning, and policymaking generates concerns or controversies over public health in relation to the configuration of public space and infrastructures (such as location of public schools, urban mobility, and energy supply). Using data as a quantitative measure for the purpose of governing urban air may rub against bodily experiences of sensing pollution that are impacted by personal as well as collective values in Denmark, including coziness (in Danish *hygge*), comfort, or convenience (Shove 2003; Bille

2019). Or it may create data frictions when CPH-UU decides that the PAV is not the only appropriate technology for them, because they wish to submit bodily experiences as nuisance reports to the Environmental Protection Agency.

Data is frequently regarded to be a key component in understanding and witnessing environmental change. Witnessing in the traditional sense, however, is rarely enough when it comes to producing testimony about air pollution as environmental change. Witnessing the environment cannot take place in the form of singularized testimony. It makes little sense to present a single observation of a particle, or even a specific count. This field of research, we argue, is one where the ability to act as witness demands both data and a collective effort of interpretation and purpose (see also Fortun et al. 2016). Our aim in this article has been to discuss how data then operates in collective configurations of processes of witnessing. The modes we have discussed are all based on the employment of digital tools for the collection and organization of data, and they all contribute to different degrees to enacting processes of data witnessing, whereby we refer to exactly this collective configuration afforded by aggregates of data. The key argument is that data alone is not enough in this configuration, and neither is simply more data. Rather, data witnessing—in this case analytically distinguished by a modest, imperial, or guerrilla character—can help us along where we have found that other concepts were more limited, because the struggle over air pollution in Copenhagen is about *more than* data as evidence or information. The three types of data witnessing diverge in terms of the scale of their measurements, the specific types of technology employed, and in the politics that they afford, but they also intersect in the general need to have and to present data as a currency in the political domain over the definitions of air pollution and air quality (Shapiro and Kirksey 2017: 488). We here distinguish between the three different types of data witnessing in order, more broadly, to contribute to an understanding of what both data and witnessing "do" when a social network

of the state, scientists, corporations, civil society, and nonhuman actors try to make sense of air pollution and environmental change. Data is embedded in such a network, and it is by paying attention to data's behavior within the network that we learn that while more data is desired by all, it is when data is mobilized in collective efforts that it becomes a powerful witness of environmental change.

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